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BRONZE AGE SUBSISTENCE STRATEGIES IN THE SOUTHEASTERN CARPATHIAN BEND AREA, ROMANIA: RESULTS FROM STABLE ISOTOPE ANALYSES

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Bronze Age subsistence strategies in the southeastern Carpathian Bend area, Romania: results from stable isotope analyses

Ülle Aguraiuja, Mihai Constantinescu, Angela Lamb, Clive Bonsall

Abstract

Here we report the results of stable carbon and nitrogen isotope analyses of human and faunal remains from two Bronze Age (Monteoru culture) sites near Buzău in Romania, in the eastern foothills of the Carpathian Mountains. The results for 54 humans from Sărata Monteoru and 10 from Cârlomăneşti indicate diets that were dominated by C_3 terrestrial resources, consistent with the archaeofaunal inventories from the sites and archaeobotanical data from the wider region. Statistically significant differences in the average $\delta^{15}N$ values of the two skeletal populations hint at a change in economic practices between early and late phases of the Monteoru culture. Consumer diets at the two sites were quantified using multiple mixing models generated with the Bayesian statistical program FRUITS (Food Reconstruction Using Isotopic Transferred Signals). The model outputs suggest the inhabitants of the later settlement, Sărata Monteoru, were less dependent on animal-derived products and relied more on cereals and legumes for energy and protein, compared to their predecessors at Cârlomăneşti. Based on changes in the faunal record we speculate that dairying may also have increased in importance between the early and later phases of the Monteoru culture.

Key words: Bronze Age, Carpathian Bend, stable isotopes, subsistence, palaeodiets

1. Introduction

Along the eastern flank of the Carpathian Mountains, in present-day Romania, is a zone of rolling hills and valleys known as the Sub-Carpathians. During the Bronze Age, this region was inhabited by sedentary farmers of the Monteoru culture. The presence of foreign goods among their archaeological remains hints at a society with trade contacts extending as far as the Baltic and the Aegean (Motzoi-Chicideanu, 1995), yet relatively little is known of the daily life of these people, including their dietary habits.

Palaeodiet studies using stable isotope data have been undertaken in Southeastern Europe since the 1980s (Murray and Schoeninger, 1988), with particularly detailed research on Mesolithic and Early Neolithic populations living along the Lower Danube in the 'Iron Gates' (e.g. Bonsall et al., 1997, 2004; Cook et al., 2001; Borić et al., 2004; Nehlich et al., 2010). For later periods, while there have been studies of Bronze and Iron Age communities along the Adriatic and the Aegean coasts (e.g. Triantaphyllou et al., 2008; Petroutsa and Manolis, 2010; Vika, 2011; Lightfoot et al., 2012, 2015), these periods in the northern Balkans have been comparatively neglected.

Bronze Age economies in southeast Europe can be very broadly characterized by an increase in cultivation intensity and crop diversity (including the spread of millet, a C_4 plant) (see Harding, 2000; Motuzaite-Matuzeviciute et al., 2013; Stika and Heiss, 2013) and a shift from caprine to cattle husbandry (Becker, 1999, 2000; Bartosiewicz, 2013). The current study aims to investigate whether similar trends can be observed in the Sub-Carpathian isotopic record.

In this paper, we present new stable isotope data for archaeological human and animal remains from two Monteoru culture sites – Sărata Monteoru and Cârlomăneşti – to assess the dietary practices of these Bronze Age communities and to provide quantitative estimates of plant *vs* animal foods in Monteoru diet.

2. Archaeological background

The Monteoru culture is one of the richest Bronze Age cultures in Southeast Europe, and one of the most thoroughly researched (Nestor, 1933; Vulpe, 1995; Motzoi-Chicideanu, 2011). The two sites included in our study, although only 12km apart, represent different phases in the evolution of the Monteoru culture (**Figure 1**).

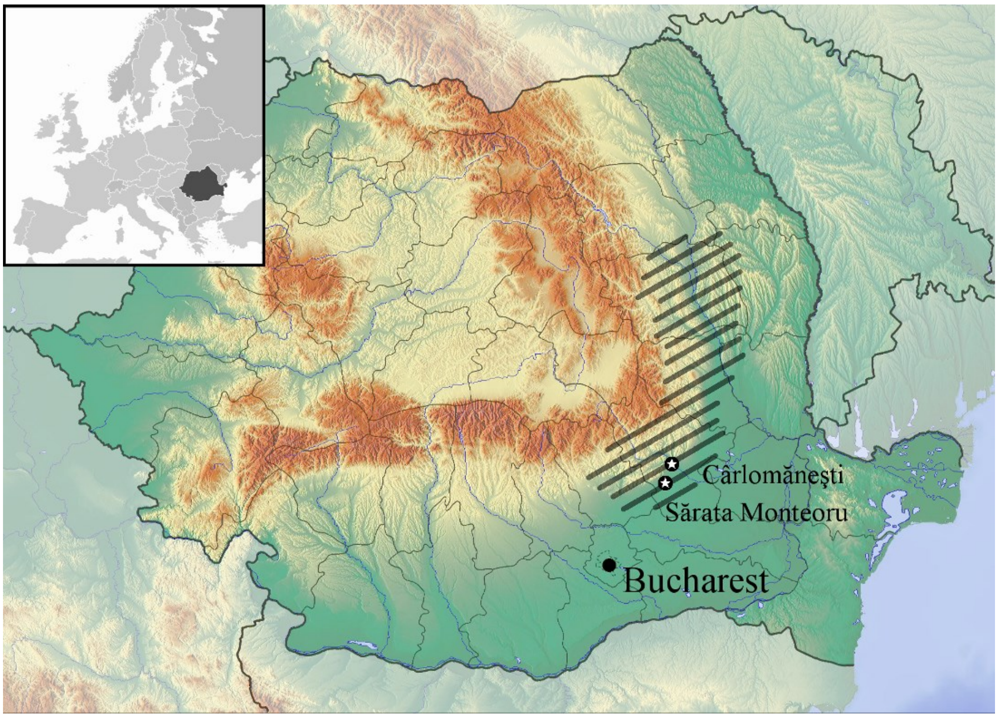

Figure 1. *Map of Romania showing the area of the Monteoru culture and the locations of Sărata Monteoru and Cârlomăneşti ('Location map of Romania' by Wikimedia Commons user Dr Brains used under GNU Free Documentation Licence 1.2, modified by Ü. Aguraiuja)*

The type site, Sărata Monteoru, is a multi-layer, fortified, hilltop settlement spanning the period from the Early Bronze Age to the end of the Middle Bronze Age, and has several associated cemeteries – three on lower slopes of the same hill, and one on an adjacent hillslope. Only the largest cemetery (no. 4) has been adequately published (Maximilian, 1962; Bârzu, 1989). Pottery typology and ^{14}C dating (four unpublished radiocarbon dates obtained by Mihai Constantinescu) place this cemetery in the middle of the second millennium BC, ca. 1750–1500 cal BC. Although more than half the graves documented in cemetery no. 4 have no grave goods, there are numerous 'rich' graves containing objects made of valuable or exotic materials, such as bronze, gold, glass paste and amber (Bârzu, 1989).

The site of Cârlomăneşti has a similar environmental setting to Sărata Monteoru, comprising a hilltop settlement (*The Citadel*) with a cemetery located on an adjacent hill, the La Arman plateau. Only one radiocarbon date is available for the settlement, which falls around 1600 cal BC (Motzoi-Chicideanu et al., 2012b), whereas 14 skeletons from the cemetery were radiocarbon dated between ca. 2280–1800 cal BC (Motzoi-Chicideanu and Chicideanu-Şandor, 2015). However, a significant part of the cemetery remains unexcavated, and may contain burials from the later period, as suggested by the discovery of a grave with Late Monteoru ceramics c. 300m from the excavated area. Thus, it is likely that the cemetery and the settlement are contemporaneous (Constantinescu, personal observation). The range of funerary goods recovered at Cârlomăneşti is similar to that found at Sărata Monteoru cemetery no. 4, although there are some differences in burial customs and grave constructions – for example, at Cârlomăneşti there were numerous collective graves and secondary burials, and many graves had stone structures such as stone-filled pits covered with small stone mounds, cists, or catacombs, often attributed to eastern influence (Motzoi-Chicideanu, 2011; Motzoi-Chicideanu et al., 2012a).

Zooarchaeological evidence from Monteoru culture sites points to a focus on cattle and caprine husbandry, supplemented by occasional hunting (Becker, 1999, 2000). Cultivation of several varieties of cereals and pulses is evidenced by the presence in archaeobotanical assemblages of emmer, einkorn, spelt, bread and durum wheat, barley, rye and gold-of-pleasure, and pea and bitter vetch (Cârciumaru, 1983, 1996). Although millet (the only regularly grown C_4 plant in prehistoric Europe) has not been reported from Monteoru culture sites, direct dating of millet grains indicates that it was cultivated in some areas of Southeast Europe as early as the Middle Bronze Age, c. 1600 cal BC (Motuzaite-Matuzeviciute et al., 2013).

Aquatic resources would have been available in rivers and streams of the surrounding landscape, although Sărata Monteoru and Cârlomăneşti are some distance (10 and 2.8 km, respectively) from the only large river in the region, the Buzău River. While fish and shellfish may have been consumed on occasion, their remains were not found among the faunal material from the sites, suggesting they are unlikely to have been more than a very minor component of the diet.

3. Stable isotope analysis for dietary reconstruction

Stable isotopes of carbon and nitrogen, analysed from bone collagen, are commonly used in archaeological research to estimate the proportion of marine *vs* terrestrial, or plant *vs* animal resources at both the individual and population level. Carbon isotope ratios ($\delta^{13}C$) can be used to distinguish between marine and terrestrial sources of carbon, but also between diets based on either C_3 or C_4 plants. Humans living on C_3 plants or their consumers have bone collagen $\delta^{13}C$ values around -20‰, while those relying mainly on C_4 resources exhibit much higher values around -10‰; elevated $\delta^{13}C$ values also result from regular consumption of marine foods (Schoeninger and DeNiro, 1984; Ambrose and DeNiro, 1986; Sealy, 2001). Fish inhabiting freshwater rivers and lakes exhibit widely varying C-isotope signatures. The $\delta^{13}C$ of fish bones from Mesolithic and Early Neolithic sites in the Iron Gates of the Danube, for example, was found to range between -26.3‰ and -15.7‰ (Bonsall et al., 1997), while Fuller et al. (2012) reported bone collagen $\delta^{13}C$ values for freshwater and anadromous fish from historical period sites in Belgium of between -28.2‰ and -14.1‰.

Nitrogen isotope ratios ($\delta^{15}N$) primarily reflect the trophic level of the organism – with every step up the food chain there occurs an enrichment of ca. 3-6‰ in ^{15}N between the food source and its consumer (Bocherens and Drucker, 2003; Hedges and Reynard, 2007). This results in plants having the lowest and top carnivores the highest $\delta^{15}N$ values. The longest food chains and thus the highest $\delta^{15}N$ values are seen in aquatic (both freshwater and marine) ecosystems (Schoeninger and DeNiro, 1984).

While $\delta^{15}N$ in animal tissues varies in a relatively predictable manner, a broad range of biogeochemical processes can influence the N isotopic composition of plants and soils at the base of the food chain. Perhaps the most important of these for agricultural societies is the effect of animal-derived fertilizers on plant $\delta^{15}N$ ratios (see Szpak [2014] for a review). While elevated (up to 5–6‰) crop $\delta^{15}N$ values have been reported for charred plant remains from prehistoric European contexts (e.g. Fraser et al., 2011, 2013; Bogaard et al., 2013; Vaiglova et al., 2014; Bogaard, 2015), the extent to which manuring affects plant $\delta^{15}N$ values seems to be highly variable, depending on the type and amount of the fertilizer and the duration of the application, with more extensive and long-term manuring practices resulting in more positive values. On occasions where high-intensity manuring has affected plant $\delta^{15}N$ values, misinterpretation of human stable isotope data can result in the overrepresentation of animal protein in human diets, as herbivores consuming (unmanured) forage may be indistinguishable from manured crops based on their collagen $\delta^{15}N$ values alone.

4. Materials and methods

Fifty-four individuals from Sărata Monteoru cemetery no. 4 and 10 individuals from Cârlomăneşti – La Arman were selected for stable $\delta^{13}C$ and $\delta^{15}N$ analysis. A rib bone was sampled from most individuals, although other skeletal elements were used if a rib was not available. Samples were selected to include both sexes, various age groups, and different 'social groups' (based on the presence and amount of grave goods). Additionally, animal bones recovered from graves in cemetery no. 4 (n=17) and from the Monteoru period settlement at Cârlomăneşti (n=39) were sampled to provide a regional terrestrial baseline of faunal isotope values. Animal bones from Sărata Monteoru are believed to relate to burial activities (e.g. grave goods or remains of feasting), although they were not documented during the original excavations. Faunal samples from Cârlomăneşti lack a direct connection with the human burials, as they were recovered from the settlement site near the cemetery, but they are assumed to be representative of the type of animal protein consumed by the local inhabitants.

Approximately 1g of bone was cut from each of the human and animal bones selected for analysis, using a Dremel multitool fitted with a diamond cutting wheel. Collagen for stable isotope analysis was extracted at the University of Edinburgh Bone Chemistry Laboratory. Bone samples were first cleaned of adhering sediment and 1-2mm removed from exposed surfaces using a sterile scalpel blade, followed by ultrasonication in ultrapure (MilliQ^{TM}) water. After drying, the cleaned samples were weighed and then subjected to standard acid/base/acid (ABA) pre-treatment at room temperature, comprising demineralization in 1M HCl, followed by 0.2M NaOH wash for 20 minutes to remove humic acids, and a final 1M HCl wash for 1 hour to remove any secondary carbonates that may have formed during NaOH treatment – after each step, the samples were rinsed three times with ultrapure water. The residue was gelatinized in a pH 3 solution at 80°C for approximately 20 hours. The resulting solution was filtered, evaporated until about 10ml remained, freeze-dried, then weighed to determine percent yield.

Collagen samples were measured for $\delta^{13}C$ and $\delta^{15}N$ at the NERC Isotope Geosciences Laboratory facility at Keyworth (UK), using a Continuous Flow-Elemental Analysis-Isotope Ratio Mass Spectrometry (CF-EA-IRMS) consisting of an elemental analyser (Flash/EA) coupled to a ThermoFinniganDelta^{Plus} XL isotope ratio mass spectrometer via a ConFlo III interface. Collagen carbon and nitrogen isotope ratios are reported in per mil (‰) relative to VPDB and AIR standards, respectively. $\delta^{13}C$ and $\delta^{15}N$ ratios were calibrated using an in-house reference material M1360p (powdered gelatine from British Drug Houses) with expected delta values of -20.32‰ (calibrated against CH7, IAEA) and +8.12‰ (calibrated against N-1 and N-2, IAEA) for C and N, respectively. Analyses were run in duplicate and the average 1-sigma standard deviation of the duplicates was $\delta^{13}C=\pm0.06$‰ and $\delta^{15}N=\pm0.05$‰. The 1-sigma reproducibility for mass spectrometry controls for these analyses was better than ±0.14‰ for $\delta^{13}C$ and ±0.06‰ for $\delta^{15}N$.

5. Results

The stable isotope data for the human and animal bone samples analysed are presented in **Tables 1 & 2** and **Figures 2 & 3**.

Collagen yields for all samples were >1% and atomic C:N ratios between 3.2 and 3.4, indicative of well-preserved collagen (van Klinken, 1999). Most samples also had elemental concentrations within the range of ≥30% for %C and ≥10% for %N defined by van Klinken (1999).

In three cases, %C and %N were below that range, but still within the accepted lower limits of 13 for %C and 5 for %N (Ambrose, 1990). Since these samples also had C:N ratios indicative of well-preserved collagen, and the values themselves do not seem abnormal, they were not discarded.

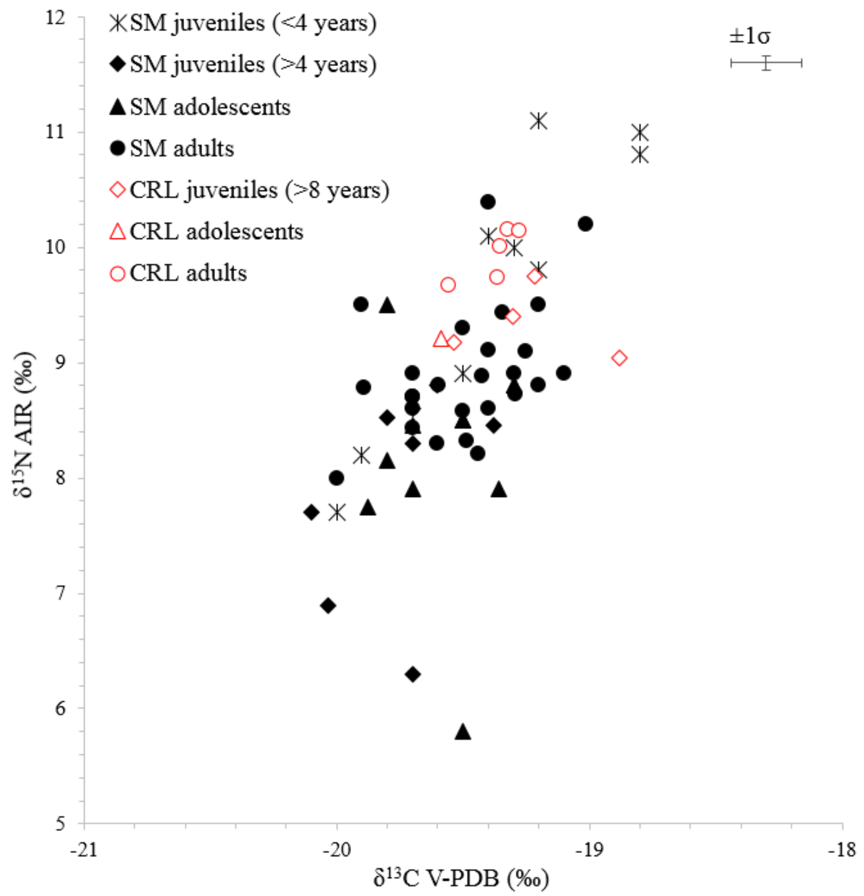

Figure 2. *Scatterplot of human $\delta^{13}C$ and $\delta^{15}N$ values. SM=Sărata Monteoru, CRL=Cârlomăneşti*

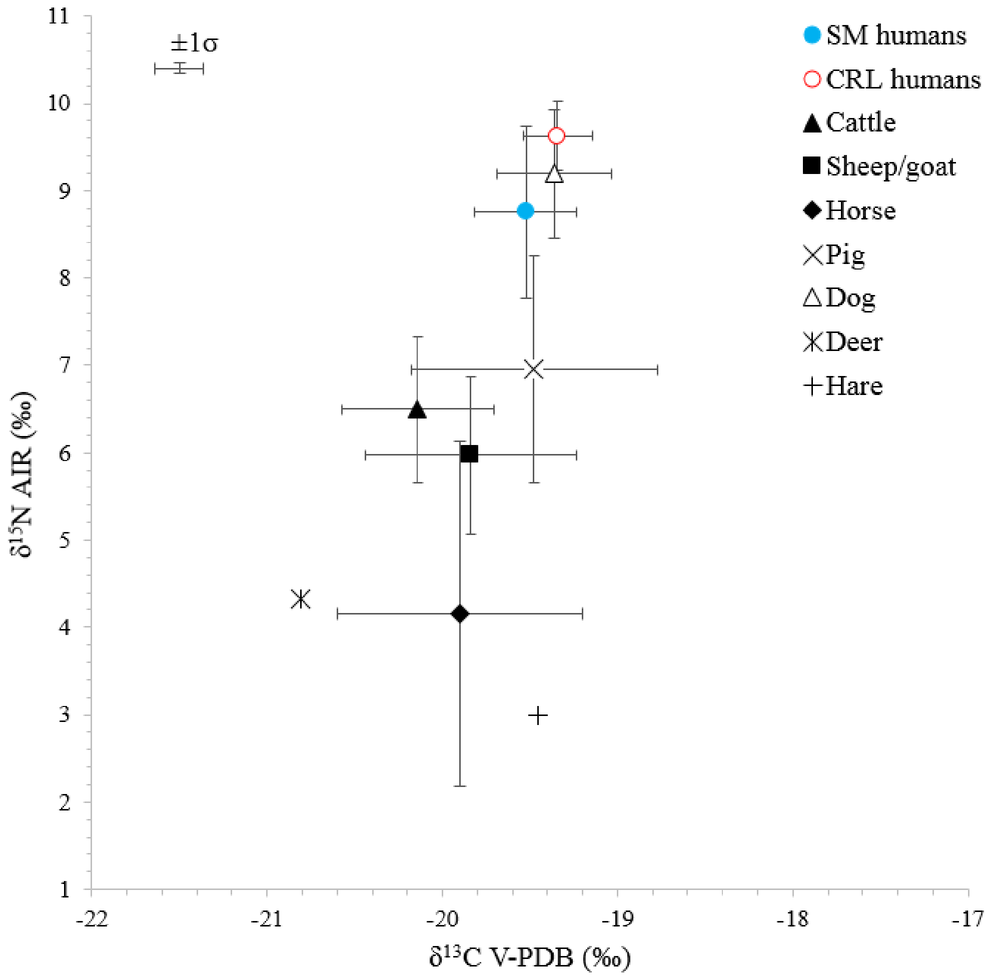

Figure 3. *Scatterplot of human and animal average $\delta^{13}C$ and $\delta^{15}N$ values, 1SD marked with error bars. Deer and hare ratios presented as individual values. SM=Sărata Monteoru, CRL=Cârlomăneşti*

Table 1. *Stable isotope results for human bone collagen from Sărata Monteoru and Cârlomăneşti.*

Burial no.	Age	Sex	Grave goods	$\delta^{13}C_{V\text{-}PDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	%C	%N	at C:N
				Sărata Monteoru				
12	9-11	N/A	Rich	-19.7	6.3	41.6	14.7	3.3
13	Adult	F	No	-19.9	9.5	29.6	10.4	3.3
24	1.5-2	N/A	No	-19.2	9.8	41.1	14.5	3.3
35a	17-19	F	Rich	-19.5	8.5	39.1	13.9	3.3
35b	1.5-2	N/A	Rich	-19.2	11.1	41.3	14.8	3.3
40	17-19	F	Rich	-19.5	5.8	39.4	13.8	3.3
41	7-9	N/A	No	-20.1	7.7	42.0	14.8	3.3
46	16-18	N/A	N/A	-19.8	9.5	32.7	11.4	3.4
48	Adult	?	Few	-19.7	8.4	41.4	14.6	3.3
50	1-3	N/A	Few	-18.8	10.8	36.5	12.8	3.3
53	Adult	F	No	-19.3	8.7	40.7	14.6	3.3

54a	Adult	F	No	-19.7	8.7	40.3	14.4	3.3
61	17-19	F	No	-19.4	7.9	42.1	14.9	3.3
62	Adult	M	No	-19.4	9.1	41.7	14.7	3.3
63	19-21	F	Rich	-19.9	7.8	40.4	14.2	3.3
64	Adult	F	No	-19.6	8.8	42.1	14.8	3.3
65	Adult	?	No	-19.3	9.1	41.6	14.8	3.3
66	Adult	?	No	-19.5	8.3	41.4	14.7	3.3
68	Adult	M	Few	-19.4	8.9	41.3	14.7	3.3
69	15-17	?	Few	-19.3	8.8	40.7	14.4	3.3
70	8-10	N/A	No	-19.4	8.5	41.6	14.8	3.3
71	Adult	M	Rich	-19.1	8.9	41.5	14.6	3.3
72	7-9	N/A	Rich	-20.0	6.9	41.5	14.6	3.3
74	Adult	F	No	-19.0	10.2	41.2	14.4	3.3
75a	Adult	F	No	-19.2	9.5	41.7	14.7	3.3
75b	1.5-2	N/A	No	-18.8	11.0	39.2	13.9	3.3
77	Adult	M	Few	-19.3	8.9	39.9	14.0	3.3
78	Adult	M	Few	-19.6	8.3	40.0	14.2	3.3
79	Adult	M	No	-19.7	8.6	40.4	14.2	3.3
80	2-4	N/A	Few	-19.4	10.1	39.5	13.7	3.4
81	Adult	?	Few	-19.4	8.2	41.1	14.6	3.3
82	15-17	?	Few	-19.5	8.5	39.9	14.0	3.3
85	Adult	F	No	-20.0	8.0	40.4	14.2	3.3
86	18-20	M	No	-19.7	8.5	42.2	14.8	3.3
88	7-9	N/A	Rich	-19.7	8.6	40.7	14.3	3.3
90b	1.5-2	N/A	No	-19.3	10.0	38.2	13.5	3.3
101	Adult	F	Few	-19.5	8.6	41.1	14.5	3.3
102	15-17	?	No	-19.8	8.1	39.3	13.8	3.3
105	Adult	F	Rich	-19.7	8.9	42.0	14.8	3.3
106	Adult	F	No	-19.4	8.6	41.2	14.5	3.3
107	Adult	F	Rich	-19.9	8.8	42.2	14.8	3.3
108	Adult	M	No	-19.4	10.4	42.2	14.8	3.3
112	18-20	M	No	-19.3	8.8	40.8	14.5	3.3
116	3-5	N/A	No	-19.5	8.9	39.4	13.9	3.3
117	2-3	N/A	No	-20.0	7.7	39.9	13.9	3.3
119	5-6	N/A	Few	-19.7	8.3	40.8	14.4	3.3
120	9-10	N/A	No	-19.6	8.8	40.0	14.0	3.3
123	17-19	M	No	-19.7	7.9	39.0	13.7	3.3
124	2-4	N/A	No	-19.9	8.2	40.3	14.1	3.3
126	Adult	M	No	-19.5	9.3	41.3	14.7	3.3
127	Adult	M	No	-19.2	8.8	41.2	14.5	3.3
128	8-12	N/A	No	-19.8	8.5	40.8	14.3	3.3
134	Adult	F	No	-19.7	8.7	39.0	13.6	3.3
135	Adult	F	No	-19.3	9.4	40.4	14.2	3.3
	Site average			**-19.5±0.3**	**8.8±1.0**			
				Cârlomăneşti				
1	Adult	F	Rich	-19.6	9.7	42.9	15.1	3.3
2	13-15	?	Few	-19.6	9.2	42.5	15.0	3.3
5	Adult	M	Few	-19.4	9.7	42.4	14.9	3.3

19	Adult	F	Few	-19.3	10.2	42.0	14.7	3.3
24	10-12	N/A	Few	-19.5	9.2	42.4	15.0	3.3
51	9-13	N/A	Rich	-19.2	9.7	41.9	14.9	3.3
58	8-9	N/A	Few	-18.9	9.0	42.5	15.1	3.3
80a	Adult	F	Rich	-19.3	10.1	42.9	15.2	3.3
103	Adult	F	Few	-19.4	10.0	38.0	13.3	3.3
105a	8-9	N/A	Few	-19.3	9.4	41.6	15.0	3.3
	Site average			**-19.3±0.2**	**9.6±0.4**			

Table 2. *Stable isotope results for animal bone collagen from Sărata Monteoru and Cârlomăneşti. Notes: 1. Each bone sample was given a unique identification code; 2. The description 'Sheep/goat' reflects the difficulty in distinguishing sheep (*Ovis aries*) from goats (*Capra hircus*) in the animal bone assemblages from the two sites.*

Sample No.[1]	Animal[2]	Species	Comments	$\delta^{13}C_{V\text{-}PDB}$‰	$\delta^{15}N_{AIR}$‰	%C	%N	at C:N
			Sărata Monteoru					
2-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-19.4	6.1	42.2	14.8	3.3
3-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-20.0	5.9	40.0	14.1	3.3
4-SM	Pig	*Sus scrofa domesticus*	Young individual	-19.9	7.4	40.5	14.4	3.3
5-SM	Pig	*Sus scrofa domesticus*		-19.1	9.8	39.6	13.5	3.4
6-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-19.1	6.4	41.8	14.9	3.3
7-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-19.6	5.9	41.1	14.4	3.3
8-SM	Cattle	*Bos taurus*		-20.0	6.6	38.1	13.6	3.3
9-SM	Pig	*Sus scrofa domesticus*		-19.5	7.6	40.1	14.1	3.3
10-SM	Cattle	*Bos taurus*		-20.0	6.3	39.9	14.1	3.3
11-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-19.0	5.4	41.1	14.6	3.3
13-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-18.9	5.7	34.3	12.1	3.3
14-SM	Cattle	*Bos taurus*		-20.7	7.8	41.4	14.7	3.3
15-SM	Cattle	*Bos taurus*		-19.5	6.4	41.1	14.5	3.3
16-SM	Dog	*Canis familiaris*		-19.2	8.4	42.7	15.0	3.3
19-SM	Sheep/goat	*Ovis aries* or *Capra hircus*		-20.2	7.4	40.4	14.1	3.4
20-SM	Cattle	*Bos taurus*		-20.5	6.4	40.1	14.0	3.4
21-SM	Horse	*Equus caballus*		-19.9	6.4	41.1	14.4	3.3
			Cârlomăneşti					
22-CRL	Cattle	*Bos taurus*		-20.6	6.5	42.0	14.9	3.3
24-CRL	Sheep	*Ovis aries*		-20.1	5.8	41.8	14.9	3.3
25-CRL	Horse	*Equus caballus*		-19.6	4.8	16.0	5.5	3.4
26-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*	With canid gnaw marks	-19.9	6.0	41.9	14.9	3.3
29-CRL	Horse	*Equus caballus*		-19.5	2.8	42.4	15.0	3.3

30-CRL	Cattle	*Bos taurus*	Young individual	-20.3	7.7	36.7	13.0	3.3
31-CRL	Pig	*Sus scrofa domesticus*		-13.5	6.2	42.4	15.3	3.2
32-CRL	Pig	*Sus scrofa domesticus*	With canid gnaw marks	-18.5	5.2	41.7	15.1	3.2
33-CRL	Deer	*Cervus* sp.		-20.8	4.3	28.8	10.2	3.3
34-CRL	Pig	*Sus scrofa domesticus*		-19.5	7.9	26.2	9.1	3.4
35-CRL	Dog	*Canis familiaris*		-20.0	9.8	39.9	14.3	3.3
36-CRL	Pig	*Sus scrofa domesticus*		-18.6	6.3	41.4	14.9	3.2
37-CRL	Cattle	*Bos taurus*		-20.2	5.6	41.7	15.0	3.2
39-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*		-16.4	6.8	34.5	12.4	3.3
40-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*		-22.1	6.4	42.5	15.5	3.2
41-CRL	Pig	*Sus scrofa domesticus*		-20.6	6.1	42.5	15.3	3.3
43-CRL	Pig	*Sus scrofa domesticus*		-20.5	5.8	42.9	15.1	3.3
44-CRL	Dog	*Canis familiaris*		-19.2	9.0	42.0	15.0	3.3
45-CRL	Hare	*Lepus* sp.		-19.5	3.0	42.4	15.0	3.3
46-CRL	Cattle	*Bos taurus*		-19.5	5.3	41.4	14.8	3.3
47-CRL	Cattle	*Bos taurus*		-20.6	8.2	33.4	11.6	3.4
48-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*		-20.3	7.6	41.7	14.7	3.3
49-CRL	Horse	*Equus caballus*		-20.9	3.2	40.5	14.4	3.3
51-CRL	Cattle	*Bos Taurus*		-20.4	6.1	41.4	14.7	3.3
52-CRL	Dog	*Canis familiaris*		-19.5	9.7	41.7	14.9	3.3
53-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*	Young individual	-20.6	6.1	41.8	14.8	3.3
55-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*	Young individual	-17.1	7.9	42.1	14.9	3.3
56-CRL	Dog	*Canis familiaris*		-19.4	7.9	41.6	14.7	3.3
57-CRL	Pig	*Sus scrofa domesticus*		-19.1	6.6	41.9	14.9	3.3
58-CRL	Pig	*Sus scrofa domesticus*		-19.4	6.7	41.6	14.7	3.3
59-CRL	Cattle	*Bos taurus*		-19.4	6.1	39.7	14.1	3.3
60-CRL	Cattle	*Bos taurus*		-20.2	7.0	38.1	13.3	3.3
61-CRL	Cattle	*Bos taurus*		-20.5	6.1	42.1	15.0	3.3
62-CRL	Dog	*Canis* sp.	Large individual (or wolf)	-19.5	8.9	41.4	14.7	3.3
63-CRL	Dog	*Canis familiaris*		-19.0	9.9	42.1	15.0	3.3
64-CRL	Cattle	*Bos taurus*		-19.8	5.5	41.8	14.9	3.3
65-CRL	Sheep/goat	*Ovis aries* or *Capra hircus*		-20.5	4.5	41.8	14.8	3.3
66-CRL	Dog	*Canis familiaris*		-19.1	9.8	42.6	15.0	3.3
67-CRL	Sheep/goat	*Ovis aries* or	With canid	-20.4	4.9	42.2	15.0	3.3

Capra hircus	gnaw marks

6. Discussion

6.1. Sărata Monteoru

The average isotope values for all Sărata Monteoru individuals (n=54) were -19.5±0.3‰ for $\delta^{13}C$ and +8.8±1.0‰ for $\delta^{15}N$ (**Table 1**, **Figure 3**). This is consistent with a terrestrial diet based on C_3 plants and plant consumers.

While the $\delta^{13}C$ range is relatively small (-20.1‰ to -18.8‰), there is significant variation in $\delta^{15}N$ values (from +5.8‰ to +11.1‰). The highest and lowest $\delta^{15}N$ values generally belong to juveniles (here defined as between 0-15 years), although excluding the juveniles has little effect on mean $\delta^{13}C$ and $\delta^{15}N$ values (-19.5‰ ±0.2‰ and +8.7‰ ±0.8‰, respectively).

Burial no. 40 (17–19-year-old female) is an outlier, with an exceptionally low $\delta^{15}N$ value of +5.8‰. The quality indicators for this sample are within accepted limits and, if not due to contamination or measurement error, this result would imply an almost exclusively plant-based diet. For modern vegans, hair keratin $\delta^{15}N$ values as low as +5.5‰ have been reported (Petzke et al., 2005; see also O'Connell and Hedges, 1999), but since human hair has been shown to be on average 0.86‰ lower in $\delta^{15}N$ than bone collagen from the same individual (O'Connell et al., 2001), none of the modern vegans would likely have had bone collagen values as low as that seen in the Sărata Monteoru outlier.

Among adolescents (here defined as from the age 15 onwards) and adults, 17 females and 12 males could be identified. The average values for adult females (-19.6‰ ±0.3‰; +8.6‰ ±1.0‰) and males (-19.4‰ ±0.2‰; +8.9‰ ±0.6‰) were similar; removing the outlier (burial 40) mentioned above from the female group would result in almost identical mean $\delta^{15}N$ values for both groups (mean female $\delta^{15}N$ without the outlier is +8.8‰ ±0.6). With or without the outlier, there were no statistically significant differences in $\delta^{13}C$ or $\delta^{15}N$ related to the sex of the individual (Mann-Whitney U test, $p>0.05$ for both variables).

$\delta^{13}C$ and $\delta^{15}N$ values also showed no statistically significant differences between juveniles, adolescents and adults (Kruskal-Wallis H test, $p>0.05$ for both variables). However, the difference would be statistically significant if juveniles were separated into two groups: those under 4 years old (n=9, mean values of -19.3‰ and +9.7‰); and those over 4 years old (n=8, mean values of -19.8‰ and +7.9‰) (Kruskal-Wallis H test, H=7.392 , d.f.=2, p=0.025 for $\delta^{13}C$, and H=10.739, d.f.=2, p=0.005 for $\delta^{15}N$; post hoc analyses showed the difference to lie between the younger and older juvenile groups for both $\delta^{13}C$ [p=0.022] and $\delta^{15}N$ [p=0.003]).

The higher $\delta^{15}N$ (and $\delta^{13}C$) values of infants reflect the well-documented breastfeeding effect (see Fuller et al., 2006). Here, infants display $\delta^{15}N$ values up to 2.5‰ higher (and up to 1.2‰ for $\delta^{13}C$) compared to the female mean, with elevated values starting to drop from age 3 years onwards.

The lower $\delta^{15}N$ values for older juveniles have been documented in other studies (e.g. Richards et al., 2002; Nitsch et al., 2011), and are sometimes attributed to the childhood diet containing lower trophic-level foods (e.g. cereals) as weaning foods (Tsutaya and Yoneda, 2013). An alternative explanation for the observed lower $\delta^{15}N$ values of older children involves the influence of positive nitrogen balance during growth (Katzenberg and Lovell, 1999; Fuller et al., 2004). However, Waters-Rist and Katzenberg (2010) concluded that the effects of growth (i.e. positive nitrogen balance) are too minor to significantly affect $\delta^{15}N$ values in juvenile bone collagen.

The quality and quantity of grave goods has traditionally been associated with social status, with a more impressive funerary inventory taken as an indicator for wealth, power and/or prestige. However, differentiating burials based on the number of grave goods is subjective, as the quantity of grave goods and their value to the deceased or to the people who buried them may have been unrelated either to wealth or the status of the individual. In the current project, a distinction was made between those buried without grave goods, those buried with 'few' grave goods (consisting of only ceramic vessels or a single artefact), and those buried with a 'rich' inventory (consisting of two or more artefacts, at least one of which was made from a material other than ceramics). The isotope data show no statistically significant differences between any of these groups ($p>0.05$ for all variables). The lack of a correlation between isotope ratios and the number of grave goods implies that those members of the community buried without grave goods did not consume significantly (i.e. isotopically) different diets from those buried with funerary objects.

6.2. Cârlomăneşti

The average isotope values for all Cârlomăneşti individuals (n=10) were -19.3‰ (±0.2‰) for $\delta^{13}C$ and +9.6‰ (±0.4‰) for $\delta^{15}N$ (**Table 1**, **Figure 3**). Cârlomăneşti human values display a more restricted range compared to Sărata Monteoru, but this may be an effect of the small sample size. Given the small data set, no statistical analyses were conducted; however, it is worth noting that the $\delta^{13}C$ and $\delta^{15}N$ values of the one adult male individual fall entirely within the range of the four females from the same site. The Cârlomăneşti sample set did not include any infants (i.e. those under 4 years of age), but mean values for older juveniles (n=4) and adults/adolescents (n=6) follow a similar trend to Sărata Monteoru where adult $\delta^{15}N$ values are slightly higher than those of younger individuals. All individuals analysed from Cârlomăneşti were buried with grave goods, but there are no clear differences in the isotope values of burials according to the number or type of items included in the grave.

6.3. Faunal isotope values

Cârlomăneşti faunal samples (n=38) showed a much wider range of $\delta^{13}C$ and $\delta^{15}N$ values (-13.5‰ to -22.1‰ for $\delta^{13}C$, +2.8‰ to +9.9‰ for $\delta^{15}N$) compared to Sărata Monteoru (n=17) (-18.9‰ to -20.7‰ for $\delta^{13}C$, +5.4‰ to +9.8‰ for $\delta^{15}N$), however, the two ranges overlap and the mean values for livestock (cattle, caprines, pigs) from the two sites are not statistically different (Cârlomăneşti -19.6‰ [±1.7‰], +6.3‰ [±0.9‰]; Sărata Monteoru -19.7‰ [±0.5‰], +6.7‰ [±1.1‰], for $\delta^{13}C$ and $\delta^{15}N$, respectively) (**Table 2**). The greater range for Cârlomăneşti may be influenced by the larger sample size, or by the archaeological material originating from various Monteoru-era layers of the settlement site (and thus potentially representing a longer period).

There is considerable variation in faunal $\delta^{15}N$ values for both sites, and in $\delta^{13}C$ values for Cârlomăneşti. Some of the higher $\delta^{15}N$ values may originate from suckling animals (which would thus display the nursing effect), or from selective consumption of manured plants with elevated $\delta^{15}N$ values. The lowest $\delta^{15}N$ values were seen in wild herbivores but also in (some) horses. $\delta^{13}C$ values for herbivores were generally consistent with diets based on C_3 plants. However, there are several outliers, all from Cârlomăneşti: two caprines (sheep or goat) have $\delta^{13}C$ values of -16.4‰ and -17.1‰, which suggest a significant contribution to diet from C_4 resources; while one pig has the highest $\delta^{13}C$ value (-13.5‰) of any sample analysed. Since none of the humans nor any of the other ungulates display such high $\delta^{13}C$ values, it seems likely these animals were distinct from the 'regular' Monteoru herds, suggesting there was movement of livestock over large distances through long-distance herding, trade activities, or gift exchange; alternatively, the outliers could represent wild/feral forms. A fourth outlier is another caprine with a $\delta^{13}C$ value of -22.1‰, >1‰ lower than measured in any other faunal sample from either site (including the two wild herbivores with $\delta^{13}C$ values as low as -20.8‰).

Dogs were kept already by the Mesolithic fishing communities of the Iron Gates (Bökönyi, 1972), and their importance in Monteoru society is reinforced by their constant presence in archaeozoological assemblages from the Carpathians from the Eneolithic onwards (Becker, 1999, 2000). Dog isotope values from both sites are similar to those of humans (on average -19.4 ±0.3‰ [$\delta^{13}C$]; +9.2 ±0.7‰ [$\delta^{15}N$]), while their $\delta^{15}N$ values are significantly higher than those of the (domestic and wild) herbivores analysed (Kruskal–Wallis H test, H=26.626, d.f.=5, $p<0.0001$). These data are consistent with the dogs having been fed (or allowed to scavenge) on human food waste that included a significant amount of animal protein, and this is supported by numerous finds from Monteoru settlements of animal bones (e.g. of cattle, pig, caprines) with canid gnaw marks (Becker, 1999, 2000), including three bones from Cârlomăneşti (two caprines and one suid) sampled for the current study (Aguraiuja, personal observation). While Becker (2000) reported cut-marks on canid bones from Monteoru culture sites (including Sărata Monteoru), the similarity of dog-human $\delta^{15}N$ ratios suggests that dog meat was not consumed in significant quantities by humans here.

6.4. Inter-site differences

The mean isotope values for all humans from Sărata Monteoru (-19.5‰ ±0.3‰ for $\delta^{13}C$ and +8.8‰ ±1.0‰ for $\delta^{15}N$) and Cârlomăneşti (-19.3‰ ±0.2‰ and +9.6‰ ±0.4‰) are statistically significantly different for $\delta^{15}N$ (Mann-Whitney U test, U=447, p=0.001) but not for $\delta^{13}C$ (Mann-Whitney U test, U=370, p=0.063), and this is also true when juvenile individuals are excluded. If the youngest individuals (i.e. under 4-year-olds) are excluded, then the differences are statistically significant for both $\delta^{13}C$ and $\delta^{15}N$ ($p<0.02$ for both variables).

The Sărata Monteoru population is characterised by slightly lower average $\delta^{13}C$ and noticeably lower $\delta^{15}N$ values compared to Cârlomăneşti. These differences are unlikely to be due to variations in local baseline isotope values, since faunal isotope values from the two sites are similar. **Figure 3** displays the average values for humans (excluding juveniles) from both sites with 1SD error bars, plotted against mean values for animals from both sites (excluding the above-mentioned outliers in the faunal data set with unusual $\delta^{13}C$ values).

At Sărata Monteoru, cattle and caprines – the principal livestock species, according to their dominance in Monteoru archaeozoological assemblages (see Becker, 1999, 2000) – have average $\delta^{15}N$ values 2.3‰ lower than humans, while for Cârlomăneşti $\Delta^{15}N$ between livestock and human averages is 3.6‰. Given livestock $\delta^{15}N$ values are similar between the two sites, the higher human $\delta^{15}N$ values for Cârlomăneşti can be explained in several ways:

A. The inhabitants of the earlier site, Cârlomăneşti, regularly consumed more animal protein than the later, Sărata Monteoru, community;

B. The two populations had diets with similar amounts of animal protein, but the inhabitants of Sărata Monteoru consumed much more animal protein in the form of dairy products, which tend to be slightly depleted in both ^{13}C and ^{15}N compared to meat from the same animal (Nardoto et al., 2006; Huelsemann et al., 2013);

C. Both communities consumed similar proportions of plant and animal protein but the Cârlomăneşti community grew plant food for human consumption with the aid of intensive manuring;

D. Both communities consumed similar amounts of animal protein, but the inhabitants of Cârlomăneşti had a strong preference for meat from very young (suckling) animals or pork from pigs that were stall fed on food waste containing animal protein and/or protein from crops grown under intensive manuring;

E. Since Cârlomăneşti was much closer to the Buzău River, its inhabitants had greater access to freshwater fish.

Hypotheses D and E lack support from the archaeofaunal data, and so are considered unlikely. Moreover, if pigs were reared on food waste, this is more likely to have occurred at Sărata Monteoru given the comparatively high $\delta^{15}N$ values of the pigs from that site (**Table 2**).

6.5. Quantitative diet reconstruction

To further explore intra-site differences, we used the Bayesian statistical program FRUITS (Food Reconstruction Using Transferred Isotopic Signals, beta 2.1.1) (Fernandes et al., 2014) to model the diets of the skeletal populations from Sărata Monteoru and Cârlomăneşti.

Using FRUITS, it is possible to consider more than two food groups, as well as factors such as differences in protein content between food groups. The program calculates probability estimates of the proportions of different foods in diet, given the consumer's stable isotope values and those of the different food groups.

We assumed that Bronze Age diets at Cârlomăneşti and Sărata Monteoru comprised three food groups: animals, cereals and legumes. The population means (excluding juveniles) were used as the consumer values. For animals, the site average for the most commonly utilized domesticated species (cattle and caprines, excluding outliers) was used. In the absence of local plant baseline data, published isotope values of Neolithic crops from Germany, Hungary and Bulgaria (Fraser et al., 2011, 2013; Bogaard et al., 2013; Bogaard, 2015) were used as proxies. Based on these published data, cereal values were set as -24‰ and +2‰, and legume values as -24‰ and 0‰, for $\delta^{13}C$ and $\delta^{15}N$, respectively.

Two different scenarios were modelled – *unmanured plants* with 'typical' $\delta^{15}N$ values for cereals and legumes (see above), and *manured plants* with more elevated values observed in the same plants grown under intensive manuring – to allow for the possibility that regular manuring of crops intended for human consumption may have influenced the human $\delta^{15}N$ data. The values for manured plants were set as +5‰ for cereals and +2‰ for legumes, based on data from Bogaard et al. (2013), Fraser et al. (2011, 2013), and Bogaard (2015).

Table 3. *Base values applied in the FRUITS model: consumer value (site average), the different food groups, and their fractions for each dietary proxy (^{13}C, ^{15}N) along with their*

associated uncertainty (‰) (set as 1-sigma error for consumers and animals, and ±0.5 for values that were not directly measured)

	Sărata Monteoru		**Cârlomăneşti**	
	δ^{13}C (‰)	**δ^{15}N (‰)**	**δ^{13}C (‰)**	**δ^{15}N (‰)**
Consumer	-19.5 ± 0.2	8.7 ± 0.8	-19.4 ± 0.1	9.8 ± 0.4
Food groups				
Animal	-19.7 ± 0.6	6.4 ± 0.7	-20.2 ± 0.4	6.2 ± 1.0
Cereal (manured)	-24 ± 0.5	5 ± 0.5	-24 ± 0.5	5 ± 0.5
Cereal (unmanured)	-24 ± 0.5	2 ± 0.5	-24 ± 0.5	2 ± 0.5
Legume (manured)	-24 ± 0.5	2 ± 0.5	-24 ± 0.5	2 ± 0.5
Legume (unmanured)	-24 ± 0.5	0 ± 0.5	-24 ± 0.5	0 ± 0.5
Food values				
Animal protein	-21.7 ± 0.6	8.4 ± 0.7	-22.2 ± 0.4	8.2 ± 1.0
Animal energy	-27.7 ± 0.6	N/A	-28.2 ± 0.4	N/A
Cereal (manured) protein	-26 ± 0.5	5 ± 0.5	-26 ± 0.5	5 ± 0.5
Cereal (manured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Cereal (unmanured) protein	-26 ± 0.5	2 ± 0.5	-26 ± 0.5	2 ± 0.5
Cereal (unmanured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Legume (manured) protein	-26 ± 0.5	2 ± 0.5	-26 ± 0.5	2 ± 0.5
Legume (manured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Legume (unmanured) protein	-26 ± 0.5	0 ± 0.5	-26 ± 0.5	0 ± 0.5
Legume (unmanured) energy	-23.5 ± 0.5	N/A	-23.5 ± 0.5	N/A
Offsets	4.8 ± 0.5	5 ± 1	4.8 ± 0.5	5 ± 1

The isotopic composition of food group macronutrients was calculated based on previously reported offsets between macronutrient and collagen isotope values, summarized in Fernandes et al. (2014, 2015). For terrestrial animal meat, the offsets are $\Delta^{13}C_{protein\text{–}collagen}$ = -2‰, $\Delta^{13}C_{energy\text{–}collagen}$ = -8‰, $\Delta^{15}N_{protein\text{–}collagen}$ = +2‰; for cereal crops and legumes $\Delta^{13}C_{protein\text{–}collagen}$ = -2‰, $\Delta^{13}C_{energy\text{–}collagen}$ = +0.5‰. The diet-to-collagen isotopic offsets for δ^{13}C and δ^{15}N were set as 4.8±0.5‰ (Fernandes et al., 2012) and 5±1‰ (Hedges and Reynard, 2007; O'Connell et al., 2012), respectively. The full list of parameter values used for the two sites and for both scenarios is given in **Table 3**.

Table 4 provides an overview of the estimates generated by FRUITS for the four different scenarios. Scenarios 1 (Sărata Monteoru) and 3 (Cârlomăneşti) take into account the potential manuring effect on both cereals and legumes, reflected in higher plant δ^{15}N values; scenarios 2 (Sărata Monteoru) and 4 (Cârlomăneşti) consider unmanured values for plants. The estimates represent calorie contributions for each food group, the calorie contribution from each food fraction, and the calorie contribution of each food group toward an isotopic proxy (either ^{13}C or ^{15}N). The estimates for ^{13}C and ^{15}N differ due to the former including a routed carbon contribution from energy (i.e. carbohydrates and lipids). The margin of error on individual estimates ranges between 12% and 25%, which demands caution when interpreting the results. Combining the data for Proxy (Food) (%) would reduce the errors to between 10% and 15% (see **Table 4**).

Table 4. *Estimates generated by FRUITS (%) with 1-sigma error for Sărata Monteoru and Cârlomăneşti populations and for both dietary scenarios. Energy includes both lipids*

and carbohydrates. The estimates represent calorie contributions for each food group (Food [%]), the calorie contribution from each food fraction (Fraction [%]), and the calorie contribution of each food group toward an isotopic proxy (^{13}C, ^{15}N, and the weighted mean of the two) (Proxy [%])

	Sărata Monteoru		**Cârlomăneşti**	
	Scenario 1 (manured)	**Scenario 2 (unmanured)**	**Scenario 3 (manured)**	**Scenario 4 (unmanured)**
Food (%)				
Animal	19 ± 14	29 ± 15	27 ± 18	37 ± 16
Cereal	35 ± 24	38 ± 24	41 ± 25	40 ± 24
Legume	46 ± 21	33 ± 19	32 ± 19	23 ± 16
Fraction (%)				
Protein	21 ± 4	21 ± 4	20 ± 4	21 ± 4
Energy	79 ± 4	79 ± 4	80 ± 4	79 ± 4
Proxy (Food) (%)				
^{13}C (Animal)	21 ± 15	32 ± 15	30 ± 18	41 ± 16
^{13}C (Cereal)	31 ± 23	33 ± 23	37 ± 24	35 ± 23
^{13}C (Legume)	48 ± 21	35 ± 19	33 ± 19	24 ± 16
^{15}N (Animal)	26 ± 17	40 ± 16	37 ± 20	51 ± 16
^{15}N (Cereal)	20 ± 18	22 ± 19	25 ± 21	22 ± 18
^{15}N (Legume)	54 ± 20	38 ± 19	38 ± 20	27 ± 16
Combined ^{13}C+^{15}N				
Animal	23 ± 11	36 ± 11	33 ± 13	46 ± 11
Cereal	24 ± 14	26 ± 15	30 ± 16	27 ± 14
Legume	51 ± 14	36 ± 13	35 ± 14	25 ± 11

Despite the large error range, there are apparent differences in the model estimates for both sites depending on whether values for manured or unmanured plants were used. Based on high crop $\delta^{15}N$ values, some authors (e.g. Bogaard et al., 2013; Fraser et al., 2013; Vaiglova et al., 2014; Bogaard, 2015) have proposed that manuring was widely practised among Central and Southeast European farmers since the Neolithic. However, Monteoru settlements were often located on fertile black earth (chernozem) soils which tend to maintain their fertility naturally without frequent manuring. While this does not exclude the possibility that low-intensity manuring occurred incidentally, i.e. by animals grazing near the farmlands or on fallow fields, without direct data from associated plant remains it is impossible to determine the real effect (if any) of manuring on Monteoru $\delta^{15}N$ values.

As suggested above from the $\Delta^{15}N_{human-herbivore}$ values for each site, the model predicts greater reliance on animal products at Cârlomăneşti. Irrespective of whether manured or unmanured scenarios are compared, the contribution of animal-based foods to total calorie intake, total dietary protein and total dietary energy on average are 10–14% greater for Cârlomăneşti compared to Sărata Monteoru. When lower plant $\delta^{15}N$ values, characteristic of unmanured crops, are used the model predicts on average ca. 15% greater importance in both sites of animal-based protein compared to legume-derived protein.

For both sites, the model predicts that plant foods accounted for most of the calories consumed, and in most scenarios plant protein also accounted for more than half of total protein intake. Estimates for the cereal food group showed the least variability, suggesting similar contributions for both sites, irrespective of the presence or absence of a manuring effect on plant $\delta^{15}N$ values. Manured values led to greater estimated contributions from legumes to total calorie intake, with scenario 1 (Sărata Monteoru, manured plants) displaying the highest contribution of legumes to both total calorie intake (ca. 46%) and to dietary protein (ca. 54%). Even at Cârlomăneşti, for which the model predicts a lower contribution from legumes, they are still estimated to account for at least a quarter of total calorie intake, and to contribute significantly to dietary protein.

Based on archaeobotanical evidence from Southeast Europe from the Neolithic onwards, the protein-rich legumes were grown on a consistent basis throughout the region, although they are usually reported in smaller numbers compared to remains of wheat and barley (e.g. Gyulai, 1993; Cârciumaru, 1996; Monah, 2007; Reed, 2013). According to Bonsall et al. (2007), ethnohistorical sources suggest that a typical peasant farming society in Southeast Europe commonly received most of their sustenance from cultivated plants such as cereals, legumes and fruits, with only a modest contribution from dairy products (meat was regarded as luxury). This is in accordance with the model's predictions for the two Monteoru sites.

While the modelled estimates have large associated uncertainties, the results nevertheless suggest differences in the way dietary resources were utilized between the two sites, and possibly, also between the Early and Late Monteoru periods. The most likely interpretation of the available data involves a modest decrease at later-period Sărata Monteoru in dependence on animal-derived products and a greater reliance on plant carbohydrates for energy, with legumes increasing in importance as a source of dietary protein over animal protein. This trend seems consistent when comparing scenarios 1 and 3 (both sites, manured plants), 2 and 4 (both sites, unmanured plants), 1 and 4 (Sărata Monteoru manured, Cârlomăneşti unmanured), but does not hold in comparisons between scenarios 2 and 3 (Sărata Monteoru unmanured, Cârlomăneşti manured).

Given the similarities of the palaeoecological and archaeological material recovered from each site, a significant change in economic activities is an unlikely explanation for the observed differences. While no clear trend can be discerned between Early and Middle Bronze Age faunal assemblages from the Monteoru culture area, available archaeozoological evidence for the Eneolithic and Bronze Age Carpathians does indicate a shift from caprine to cattle husbandry during the Bronze Age, with cattle becoming the dominant species by the Late Bronze Age (Becker, 1999, 2000). The rise in the importance of cattle husbandry during the Carpathian Bronze Age may have increased the amount of milk available for dairy products; alternatively, a rise in the popularity of, or developments, in dairying may have led to the preferential keeping of cows. The maturity of cattle in several middle Danube sites during the second millennium BC has also been taken to imply an important role for dairy cows (Barker, 1989). Additionally, as animals kept for dairying would be slaughtered less often than those kept for meat, it would presumably reduce the amount of (cattle) meat consumed – and the calories obtained from animal products. It is thus possible that a change in dietary practices between the Early and Late Monteoru periods as represented by the two sites included in this study may have involved a shift from a more meat-based economy to a more dairy- and plant-based economy.

7. Conclusions

The results from stable carbon and nitrogen isotope analyses for Monteoru culture humans and fauna reflect a dietary regime that was dominated by C_3 terrestrial resources. The Sărata Monteoru population is characterised by significantly lower average $\delta^{15}N$ and slightly lower average $\delta^{13}C$ compared to Cârlomăneşti. Since faunal isotope values from the two sites are similar (excluding the outliers with relatively high $\delta^{13}C$ values, which could reflect movement of livestock over large distances), these differences are unlikely to be due to variation in local baseline isotope values. Estimates generated by FRUITS suggest that while plant foods – both cereals and legumes – were an important source of calories and dietary protein throughout the Monteoru period, inhabitants of the earlier settlement, Cârlomăneşti, were more dependent on animal-derived products compared to the population sampled from Sărata Monteoru.

The difference in the average $\delta^{13}C$ and $\delta^{15}N$ values of the two skeletal populations suggests a change in economic activities between the early and late phases of the Monteoru culture, possibly characterised by a shift from a more meat-based economy to a more dairy- and plant-based economy. However, as this is only the first major stable isotope study conducted on osteological material from the Romanian Sub-Carpathians, more data are needed to determine whether the observed shift is a true temporal trend or merely reflects site-specific dietary preferences.

Interpretation of the stable isotope data are constrained by the lack of associated plant remains, which are necessary to clarify the issue of the effects of manuring on human and faunal isotope ratios. There is also a need for paired ^{14}C and stable isotope measurements to more fully explore changes in dietary practices throughout the Carpathian Bronze Age. Further work is underway to explore other aspects of Monteoru culture subsistence, including sulphur isotope analysis (to investigate mobility of livestock) and incremental analysis of teeth dentine (to elucidate weaning practices).

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References

Ambrose, S. H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Arch. Sci. 17, 431–451.

Ambrose, S. H., DeNiro, M. J., 1986. The isotopic ecology of East African mammals. Oecologica. 69, 395–406.

Barker, G., 1989. Prehistoric farming in Europe. Cambridge University Press.

Bartosiewicz, L., 2013. Animals in Bronze Age Europe, in: Fokkens, H., Harding, A. (Eds), The Oxford Handbook of the European Bronze Age. Oxford University Press, Oxford, pp. 328–347.

Bârzu, L., 1989. La station de Sărata-Monteoru: La nécropole n° 4 de l'époque de bronze. Dacia N.S. 33, 39–78.

Becker, C., 1999. Domesticated and wild animals as evidenced in the Eneolithic–Bronze Age cultures Coțofeni and Monteoru, Romania, in: Benecke, N. (Ed.), The Holocene history of the European Vertebrate Fauna: Modern aspects of research, workshop held 6-9th April 1998 in Berlin, Archäologie in Eurasien 6. Rahden/Westf., Leidorf, pp. 91–105.

Becker, C., 2000. Subsistenzstrategien während der frühen Metallzeit im zentralkarpatischen Raum – neue archäozoologische Daten zur Coțofeni- und Monteoru-Kultur. Praehistorische Zeitschrift. 75(1), 63–92.

Bocherens, H., Drucker, D., 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. Int. J. Osteoarchaeol. 13, 46–53.

Bogaard, A., 2015. New insights into early farming practice and diet from stable isotope analysis of crop assemblages, in: Brink, K., Hydén, S., Jennbert, K., Larsson, L., Olausson, D. (Eds), Neolithic diversities: perspectives from a conference in Lund, Sweden. Acta Archaeologica Lundensia, 8(65), pp. 33-42.

Bogaard, A., Fraser, R., Heaton, T. H. E., Wallace, M., Vaiglova, P., Charles, M., Jones, G., Evershed, R. P., Styring, A. K., Andersen, N. H., Arbogast, R.-M., Bartosiewicz, L., Gardeisen, A., Kanstrup, M., Maier, U., Marinova, E., Ninov, L., Schäfer, M., Stephan, E., 2013. Crop manuring and intensive land management by Europe's first farmers. PNAS. 110(31), 12589–12594.

Bökönyi, S., 1972. The vertebrate fauna, in: Srejović, D. (Ed.), Europe's First Monumental Sculpture. New Discoveries at Lepenski Vir. Stein and Day, pp. 186–189.

Bonsall, C., Lennon, R., McSweeney, K., Stewart, C., Harkness, D., Boroneanţ, V., Bartosiewicz, L., Payton, R., Chapman, J., 1997. Mesolithic and Early Neolithic in the Iron Gates: a palaeodietary perspective. Journal of European Archaeology. 5(1), 50–92.

Bonsall, C., Cook, G., Hedges, R., Higham, T., Pickard, C., Radovan, I., 2004. Radiocarbon and stable isotope evidence of dietary change from the Mesolithic to the Middle Ages in the Iron Gates: new results from Lepenski Vir. Radiocarbon. 46(1), 293–300.

Bonsall, C., Horvat, M., McSweeney, K., Masson, M., Higham, T. F., Pickard, C., Cook, G. T., 2007. Chronological and dietary aspects of the human burials from Ajdovska Cave, Slovenia. Radiocarbon. 49(2), 727–740.

Borić, D., Grupe, G., Peters, J., Mikić, Ž., 2004. Is the Mesolithic–Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges. European Journal of Archaeology. 7(3), 221–248.

Cârciumaru, M., 1983. Consideraţii paleobotanice şi contribuţii la agricultura geto-dacilor. Thraco-Dacica. 4, 126–134.

Cârciumaru, M., 1996. Paleoetnobotanica. Iaşi.

Cook, G.T., Bonsall, C., Hedges, R. E., McSweeney, K., Boroneanţ, V., Pettitt, P. B., 2001. A freshwater diet-derived ^{14}C reservoir effect at the Stone Age sites in the Iron Gates Gorge. Radiocarbon. 43(2A), 453–460.

Fernandes, R., Nadeau, M.- J., Grootes, P. M., 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. Archaeol. Anthrop. Sci. 4(4), 291–301.

Fernandes, R., Millard A. R., Brabec, M., Nadeau, M.-J., Grootes, P., 2014. Food Reconstruction Using Isotopic Transferred Signals (FRUITS): a Bayesian model for diet reconstruction. PLoS ONE. 9(2), e87436.

Fernandes, R., Grootes, P., Nadeau, M.-J., Nehlich, O., 2015. Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): the case study of Ostorf (Germany). Am. J. Phys. Anthropol. 158(2), 325–340.

Fraser, R. A., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B. T., Halstead, P., Merbach, I., Poulton, P. R., Sparkes, D., Styring, A. K., 2011. Manuring and stable isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. J. Archaeol. Sci. 38, 2790–2804.

Fraser, R. A., Bogaard, A., Schäfer, M., Arbogast, R., Heaton, T. H., 2013. Integrating botanical, faunal and human stable carbon and nitrogen isotope values to reconstruct land use and palaeodiet at LBK Vaihingen an der Enz, Baden-Württemberg. World Archaeology. 45(3), 492–517.

Fuller, B. T., Fuller. J. L., Sage, N. E., Harris, D. A., O'Connell, T. C., Hedges, R. E. M., 2004. Nitrogen balance and δ^{15}N: Why you're not what you eat during pregnancy. Rapid Communications in Mass Spectrometry. 18, 2889–2896.

Fuller, B. T., Fuller, J. L., Harris, D. A., Hedges, R.E.M., 2006. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. Am. J. Phys. Anthropol. 129, 279–293.

Fuller, B. T., Müldner, G., Van Neer, W., Ervynck, A., Richards, M. P., 2012. Carbon and nitrogen stable isotope ratio analysis of freshwater, brackish and marine fish from Belgian archaeological sites (1st and 2nd millennium AD). J. Anal. At. Spectrom. 27, 807–820.

Gyulai, F., 1993. Environment and agriculture in Bronze Age Hungary. Archaeolingua, 4, Budapest.

Harding, A. F. 2000. European societies in the Bronze Age. Cambridge University Press, Cambridge.

Hedges, R. E. M., Reynard, L. M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. J. Archaeol. Sci. 34, 1240–1251.

Huelsemann, F., Koehler, K., Braun, H., Schaenzer, W., Flenker, U., 2013. Human dietary $\delta^{15}N$ intake: representative data for principle food items. Am. J. Phys. Anthropol. 152, 58–66.

Katzenberg, M. A., Lovell, N. C., 1999. Stable isotope variation in pathological bone. Int. J. Osteoarchaeol. 9, 316–324.

Lightfoot, E., Šlaus, M., O'Connell, T. C., 2012. Changing cultures, changing cuisines: cultural transitions and dietary change in Iron Age, Roman, and Early Medieval Croatia. Am. J. Phys. Anthropol. 148(4), 543–556.

Lightfoot, E., Šlaus, M., Šikanjić, P. R., O'Connell, T. C., 2015. Metals and millets: Bronze and Iron Age diet in inland and coastal Croatia seen through stable isotope analysis. Archaeol. Anthropol. Sci. 7(3), 375–386.

Maximilian, C., 1962. Sărata-Monteoru. Studiu Antropologic. Academia Republicii Populare Romîne.

Monah, F., 2007. The spread of cultivated plants in the region between the Carpathians and Dniester, 6th–4th millennia cal BC, in: Colledge, S., Conolly, J. (Eds.), The Origins and Spread of Domestic Plants in Southwest Asia and Europe. University College, London, Institute of Archaeology, pp. 111–123.

Motuzaite-Matuzeviciute, G., Staff, R. A., Hunt, H. V., Liu, X., Jones, M. K., 2013. The early chronology of broomcorn millet (*Panicum miliaceum*) in Europe. Antiquity. 87(338), 1073–1085.

Motzoi-Chicideanu, I., 1995. Fremdgüter im Monteoru-Kulturraum, in: Hänsel, B. (Ed.), Handel, Tausch und Verkehr im bronze- und eisenzeitlichen Südosteuropa, Südosteuropa-Schr. 17, Prähistorische Archäologie in Südosteuropa 11. Berlin, pp. 219–242.

Motzoi-Chicideanu, I., 2011. Obiceiuri funerare in epoca bronzului la Dunărea Mijlocie şi Inferioară. Editura Academiei Române, București.

Motzoi-Chicideanu, I., Chicideanu-Şandor, M., 2015. Câteva date noi privind cronologia culturii Monteoru. Mousaios. 20, 9–53.

Motzoi-Chicideanu et al. 2012a = Motzoi-Chicideanu, I., Chicideanu-Şandor, M., Constantinescu, M., 2012. Observatii prelimina reprivind cercetările efectuate în anii 2008–2009, 2011–2012 la cimitirul din epoca bronzului de la Cârlomănesti. Mousaios. 17, 47–61.

Motzoi-Chicideanu et al. 2012b = Motzoi-Chicideanu, I., Matei, S., Gugiu, D., 2012. O piesă de harnaşament din epoca bronzului descoperită la Cârlomăneşti-Cetăţuia. Mousaios. 17, 65–95.

Murray, M. L., Schoeninger, M. J., 1988. Diet, status, and complex social structure in Iron Age Central Europe: some contributions of bone chemistry, in: Tribe and Polity in Late Prehistoric Europe. Springer, US, pp. 155–176.

Nardoto, G. B., Silva, S., Kendall, C., Ehleringer, J. R., Chesson, L. A., Ferraz, E. S. B., Moreira, M. Z., Ometto, J. P. H. B., Martinelli, L. A., 2006. Geographical patterns of human diet derived from stable-isotope analysis of fingernails. Am. J. Phys. Anthropol. 131, 137–146.

Nehlich, O., Borić, D., Stefanović, S., Richards, M. P., 2010. Sulphur isotope evidence for freshwater fish consumption: a case study from the Danube Gorges, SE Europe. J. Archaeol. Sci. 37(5), 1131–1139.

Nestor, I., 1933. Der Stand der Vorgeschichtsforschung in Rumänien, 22, Bericht der Römisch-Germanischen Kommission.

Nitsch, E. K., Humphrey, L. T., Hedges, R. E. M., 2011. Using stable isotope analysis to examine the effect of economic change on breastfeeding practices in Spitalfields, London, UK. Am. J. Phys. Anthropol. 146, 619–628.

O'Connell, T. C., Hedges, R. E. M., 1999. Investigations into the effect of diet on modern human hair isotope values. Am. J. Phys. Anthropol. 108, 409–425.

O'Connell, T. C., Hedges, R. E. M., Healey, M. A., Simpson, A. H. R. W., 2001. Isotopic comparison of hair, nail and bone: modern analyses. J. Archaeol. Sci. 28, 1247–1255.

O'Connell, T. C., Kneale, C. J., Tasevska, N., Kuhnle, G. G. C., 2012. The diet-body offset in human nitrogen isotopic values: a controlled dietary study. Am. J. Phys. Anthropol. 149, 426–434.

Petroutsa, E. I., Manolis, S. K., 2010. Reconstructing Late Bronze Age diet in mainland Greece using stable isotope analysis. J. Archaeol. Sci. 37, 614–620.

Petzke, K. J., Boeing, H., Metges, C. C., 2005. Choice of dietary protein of vegetarians and omnivores is reflected in their hair protein ^{13}C and ^{15}N abundance. Rapid Communications in Mass Spectrometry. 19, 1392–1400.

Reed, K. A., 2013. Farmers in transition: the archaeobotanical analysis of the Carpathian Basin from the Late Neolithic to the Late Bronze Age (5000–900 BC). Unpublished PhD dissertation, University of Leicester.

Richards, M. P., Mays, S., Fuller, B. T., 2002. Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the medieval Wharram Percy site, Yorkshire, UK. Am. J. Phys. Anthropol. 119, 205–210.

Schoeninger, M. J., DeNiro, M. J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta. 48, 625–639.

Sealy, J. C., 2001. Body tissue chemistry and palaeodiet, in: Brothwell, D. R., Pollard, A. M. (Eds.), Handbook of Archaeological Sciences. Wiley, pp. 269–279.

Stika, H.-P., Heiss, A. G., 2013. Plant cultivation in the Bronze Age, in: Fokkens, H., Harding, A. (Eds), The Oxford Handbook of the European Bronze Age. Oxford University Press, Oxford, pp. 348–369.

Szpak, P., 2014. Complexities of nitrogen isotope biogeochemistry in plant-soil systems: implications for the study of ancient agricultural and animal management practices. Frontiers in Plant Science 5.

Triantaphyllou, S., Richards, M. P., Zerner, C., Voutsaki, S., 2008. Isotopic dietary reconstruction of humans from Middle Bronze age Lerna, Argolid, Greece. J. Archaeol. Sci. 35(11), 3028–3034.

Tsutaya, T., Yoneda, M., 2013. Quantitative reconstruction of weaning ages in archaeological human populations using bone collagen nitrogen isotope ratios and approximate Bayesian computation. PLoS ONE. 8(8), e72327.

Vaiglova, P., Bogaard, A., Collins, M., Cavanagh, W., Mee, C., Renard, J., Lamb, A., Gardeisen, A., Fraser, R., 2014. An integrated stable isotope study of plants and animals from Kouphovouno, southern Greece: a new look at Neolithic farming. J. Archaeol. Sci. 42, 201–215.

van Klinken, G. J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J. Archaeol. Sci. 26, 687–695.

Vika, E., 2011. Diachronic dietary reconstructions in ancient Thebes, Greece: results from stable isotope analyses. J. Archaeol. Sci. 38(5), 1157–1163.

Vulpe, A., 1995. Epoca bronzului în spaţiul carpato-dunărean, privire general, in: Petrescu Dâmboviţa, M. (Ed.), Comori ale epocii bronzului în România. Bucureşti, pp. 17–23..

Waters-Rist, A. L., Katzenberg, M. A., 2010. The effect of growth on stable nitrogen isotope ratios in subadult bone collagen. Int. J. Osteoarchaeol. 20, 172–191.